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FINAL REPORT

DATALOGGER EVALUATION

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
EXECUTIVE SUMMARY	1
EXPERIMENTAL PROCEDURE	2
Metrosonics dl-721	4
Campbell Scientific 21X	7
TEST RESULTS	9

INTRODUCTION

The purpose of this project was to determine which commercially available portable datalogger was best suited for use in cold temperatures by the Alaska Department of Transportation and Public Facilities (DOT&PF). The criteria for making the determination were twofold: (1) the datalogger had to be portable and operate accurately and continuously at cold temperatures; and (2) the datalogger had to be easily programmable and data had to be easily retrievable.

The results of this project are presented in an executive summary. A detailed explanation of the test procedure is then described. Next, a subjective overview of test results for each datalogger is presented. Appendices are included after the overview, detailing the specifications of each datalogger tested.

EXECUTIVE SUMMARY

The purpose of this project was to determine which commercially available portable datalogger was best suited to DOT&PF field use. The two stated criteria for selecting the portable datalogger were: (1) continuous and accurate datalogging at low temperatures; and (2) ease of operation (i.e., ease in programming and in data retrieval).

Information about several portable dataloggers was collected and the field of portable dataloggers narrowed to two, which were then purchased for testing. The Metrosonics dl-721 is an 8-channel, general purpose, battery-operated datalogger capable of storing over 7,200 values (see Appendix A). It was purchased at a cost of $2,595 from Metrosonics Inc., Rochester, New York. The second unit was a Campbell Scientific 21X general purpose, battery-operated datalogger/processor capable of storing 768 values, expandable up to 19,200 values. It was purchased from Campbell Scientific, Inc., Logan, Utah, at a cost of $1,950 (see Appendix B). Both dataloggers are programmable and accept voltage and current inputs. The Campbell Scientific 21X will also measure temperature using type T, E, K or J thermocouples and thermistors.

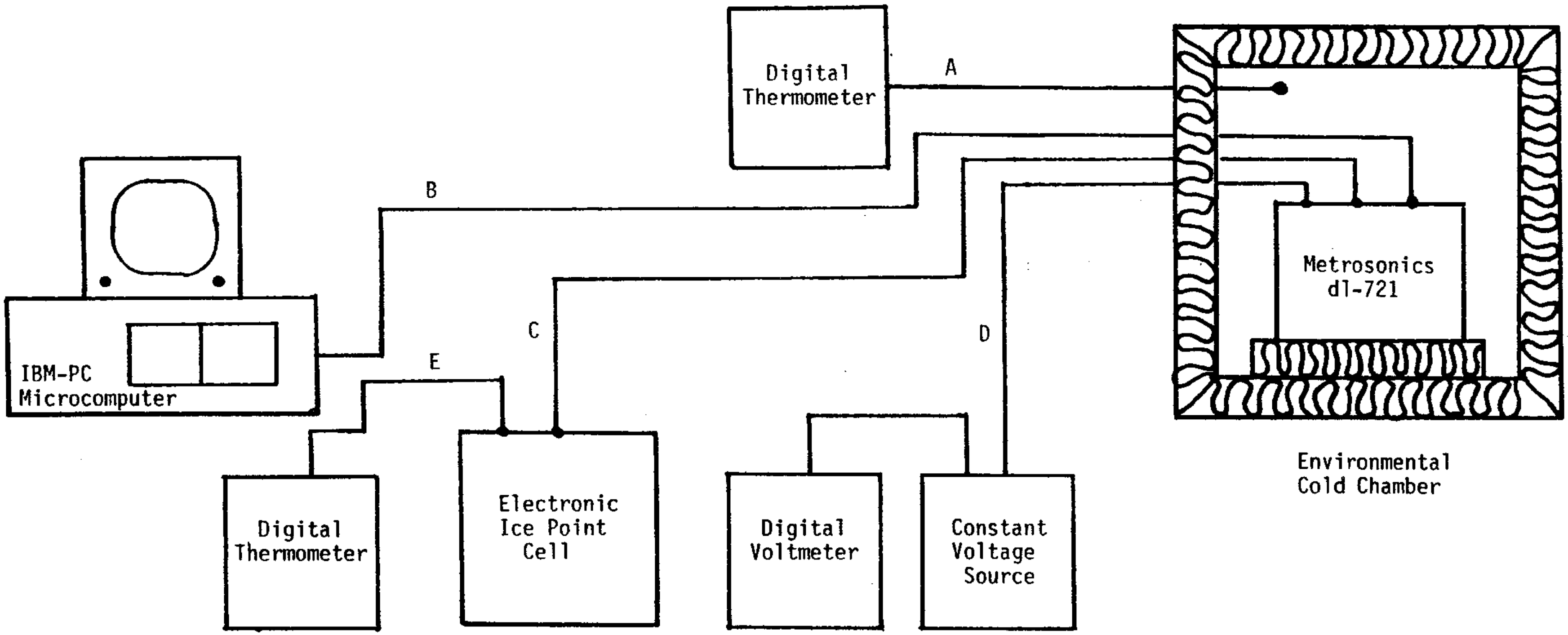
Neither the Campbell Scientific 21X nor the Metrosonics dl-721 datalogger satisfied both stated performance criteria. However, the Campbell Scientific 21X clearly outperformed the Metrosonics dl-721. With some precautions, it will log field data in a continuous and accurate manner at temperatures down to -30°F. The only significant drawback to the Campbell Scientific 21X datalogger is its lack of comprehendable documentation. If DOT&PF purchases Campbell Scientific 21X dataloggers, we highly recommend that Campbell Scientific be required to provide a comprehendable users' manual with sample programs. Lacking this, DOT&PF should contract with a second party to provide a clear and understandable users' manual. An example program is given in Appendic C for this unit.

To our knowledge, there are no other instruments that will outperform the Campbell Scienctific 21X for the required purposes.

EXPERIMENTAL PROCEDURE

To test the performance of the two dataloggers at reduced temperatures, the School of Engineering's environmental cold chamber was used. The dataloggers were generally cold soaked at 40°F, 20°F, 0°F, -20°F and -40°F. Except for test cycles 1, 3 and 4 on the Campbell Scientific 21X, a typical thermal cycle entailed cold soaking the dataloggers at all five temperatures. Cold soaking means that the datalogger temperature was allowed to come to equilibrium with the test chamber temperature. A schematic diagram of the test equipment, constant voltage source, voltmeter, ice point cell, IBM-PC microcomputer and two digital thermometers is shown in Figure 1 for testing the Metrosonics dl-721. The equipment allowed careful monitoring of cold chamber temperature, datalogger temperature, ice point cell temperature and power supply voltage. Each datalogger was set up to measure the output of a constant voltage source and the millivolt output of one or more thermocouples.

Another important aspect of datalogger performance that developed during testing was the thermal gradient within the datalogger. The magnitude of the thermal gradient is proportional to the temperature



A - Cold chamber temperature

B - Datalogging with microcomputer

C - Ice point cell temperature measured by datalogger being tested

D - Constant voltage source output measured by datalogger

E - Ice point cell temperature

Figure 1. Schematic of test equipment used with Metrosonics dl-721 datalogger.

difference between the interior datalogger and the environmental chamber. As a brief illustration, if the test chamber temperature is lowered at a rate of 100°F per hour, then the thermal gradient the datalogger experiences is greater than if the test chamber temperature is lowered at the rate of 10°F per hour. In other words, a high rate of cooling of the test chamber develops a larger, instantaneous temperature difference between the center of the datalogger and the chamber air temperature.

Metrosonics dl-721

The testing of the Metrosonics unit was performed as follows. The Metrosonics dl-721 was set up to monitor ice point cell temperature, cold chamber temperature, its own temperature and the output of the constant voltage source by attaching two type T thermocouples and a pair of leads from the constant voltage source to the dl-721. One of the thermocouples was taped to the bottom of the datalogger, which was subsequently placed on a piece of expanded polystyrene insulation inside the environmental test chamber as shown in Figure 2. The output from the thermocouple provided a close approximation to the datalogger's internal temperature. The second thermocouple was inserted in the ice point cell to provide an accurate and precise 32°F reference temperature. By connecting the datalogger to an IBM-PC microcomputer located outside the test chamber, the data being logged by the Metrosonics dl-721 could be constantly monitored. One of the digital thermometers was used to monitor the cold chamber temperature, while the other was used to check the ice point cell temperature. A digital multimeter was used to monitor the output of the constant voltage source.

Brief descriptions of our tests follow.

Test Cycle One. Test cycle one consisted of cold soaking the dl-721 datalogger for two hours at each test temperature. The datalogger failed to log data or communicate with the IBM-PC microcomputer at an internal datalogger temperature of about -30°F. Upon warming to ambient room temperature in approximately two hours, the

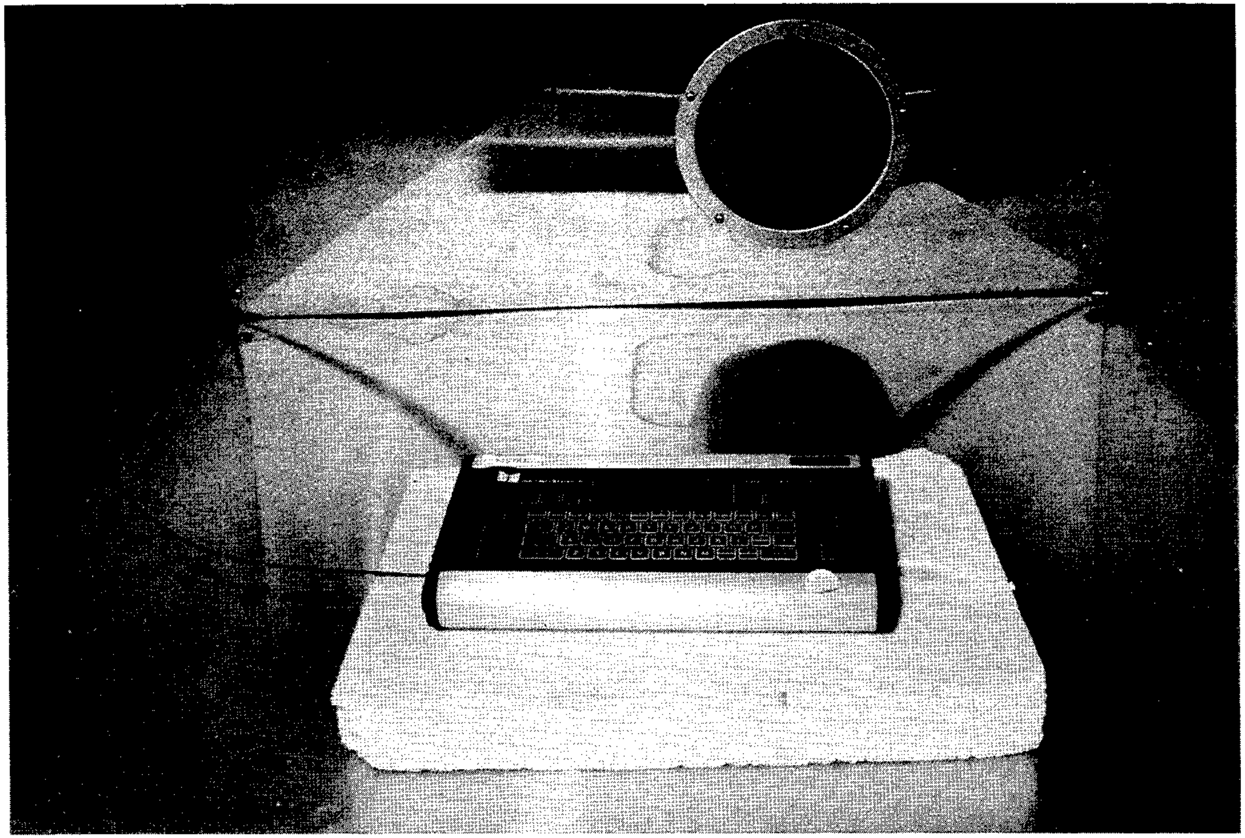


Figure 2. Metrosonics dl-721 datalogger on expanded polystyrene insulation inside environmental test chamber.

datalogger needed to undergo a "hard reset" before it would become operational again. When the Metrosonics dl-721 is reset, all program instructions and stored data from the test cycle are lost, and the clock and programmable parameters are automatically reset to their default values.

Test Cycle Two. The second test was identical to the first test except that the datalogger ceased to function normally at about -15°F. Again, a hard reset was necessary to make the unit operational and subsequently all data were lost.

Test Cycle Three. The third test was identical to the others except that the test chamber temperature was reduced from 0°F to -20°F in two equal temperature increments (cold chamber temperature decreases were spaced one hour apart), and then reduced in 5°F increments spaced one hour apart from -20°F to -30°F. The datalogger failed to function at an internal datalogger temperature of about -30°F. Again, a hard reset was necessary and all data were lost.

Test Cycle Four. The fourth test cycle was identical to the first two test cycles except: (1) the environmental test chamber temperature was cooled from 0°F to -20°F in four equal temperature reductions of 5°F spaced at half-hour intervals; (2) the chamber was cooled from -20°F to -30°F in 2.5°F temperature increments spaced 15 minutes apart; and (3) the chamber was cooled from -30°F to -40°F in 2.5°F temperature increments spaced 15 minutes apart. The dl-721 continued to operate successfully throughout the cool down portion of this test cycle. The datalogger was warmed to room temperature rapidly and had to undergo a hard reset, again resulting in a loss of data.

Test Cycle Five. The fifth test was identical to the first two test cycles except that the dl-721 was cooled to -20°F in 2.5°F increments spaced 15 minutes apart. The datalogger operated for approximately one hour at -20°F until an attempt to monitor current datalogger inputs was made with an IBM-PC microcomputer. The Metrosonics unit ceased to function and had to undergo a hard reset.

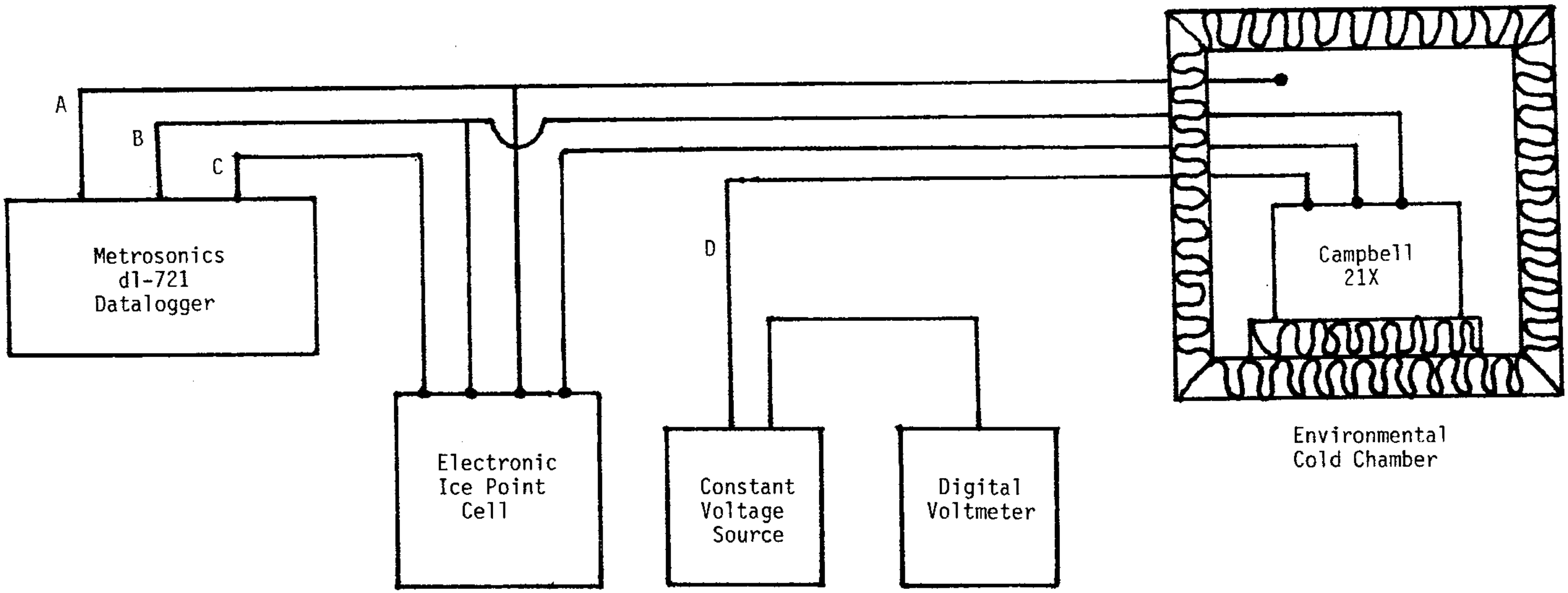
Campbell Scientific 21X

The Campbell Scientific 21X was set up to monitor cold chamber and ice point cell temperatures, its own temperature, and the output of the constant voltage source is shown in Figure 3. The instrumentation entailed attaching three type T thermocouples to the Campbell Scientific 21X datalogger and a pair of leads from the constant voltage source. The Campbell Scientific 21X has an internal isothermal block that it uses as a reference junction for all thermocouple measurements. The isothermal block temperature may be stored in memory and was used as an indication of the datalogger's internal temperature. Placed outside the environmental test chamber, the Metrosonics dl-721 was used to monitor the Campbell Scientific 21X's temperature, cold chamber temperature and output of the constant voltage source. The following is a brief description of the tests performed on the Campbell Scientific 21X.

Test Cycle One. The datalogger temperature held at -40°F for three hours. The Campbell Scientific 21X was allowed to slowly warm to room temperature over a period of several hours, and then the stored data were examined. The data appeared to become totally random at datalogger internal temperatures colder than -38°F.

Test Cycle Two. The Campbell Scientific 21X was allowed to cold soak for two hours at 40°F, 20°F, 0°F, -20°F and -40°F. It was then allowed to rapidly warm to room temperature. The stored data appeared to become random when the datalogger internal temperature was colder than -32°F. The unit did measure temperatures accurately during the cold soaking at temperatures above this point. However, during the warming portion of the cycle, several F° errors occurred in the recorded ice point temperature.

Test Cycle Three. The datalogger temperature was held at -40°F for six hours. The datalogger was then allowed to warm rapidly to room temperature. Bad data were stored at datalogger temperatures below -30°F. Again, during the warming, several F° errors occurred in measuring the ice point temperature.



A - Cold chamber temperature

B - Campbell Scientific 21X temperature

C - Ice point cell temperature measured by datalogger

D - Constant voltage source output measured by datalogger

Figure 3. Schematic of test equipment used with Campbell Scientific 21X datalogger.

Test Cycle Four. This test cycle was conducted using a replacement Campbell Scientific 21X datalogger that was purchased about six months later than the one used in the first four test cycles. The datalogger temperature was dropped to -50°F and held there for several hours. The datalogger was then allowed to warm to room temperature over a period of approximately 14 hours. The data were reasonably accurate at datalogger temperatures down to -50°F. Much of the error appears to be due to the small thermal gradient experienced by the datalogger (see Figure 4) during the warming portion of the test cycle.

TEST RESULTS

Unfortunately, neither the Metrosonics dl-721 nor the Campbell Scientific 21X datalogger totally met both of DOT&PF's stated criteria.

The Campbell Scientific 21X appears to function normally to -40°F but is actually storing what can only be described as random data when its internal temperature drops below about -30°F. Furthermore, the operating characteristics of the Campbell Scientific 21X unit degrade with continued thermal cycling. In the first test, the Campbell Scientific 21X began storing random data when it reached -38°F. After only two more test cycles, it was storing errant data after cooling to only about -30°F.

It is highly unlikely that the datalogger would be subjected to such severe temperature gradients under field conditions. Without continued extensive testing, it is impossible to determine the final extent of degradation due to thermal cycling. The final test (test cycle 4) was performed on a newer Campbell Scientific 21X and showed that the datalogger could withstand low temperatures and severe temperature gradients and still function accurately. As can be see in Figure 4, the Campbell Scientific 21X stores errant data while extremely cold and/or when experiencing a large internal temperature gradient. It is believed much of the error is due to the rate of warming which reached a maximum of 22.5°F degrees per hour. For normal field conditions (i.e., normal temperatures and reasonable fluctuations in temperature), the datalogger appears to operate in an accurate manner.

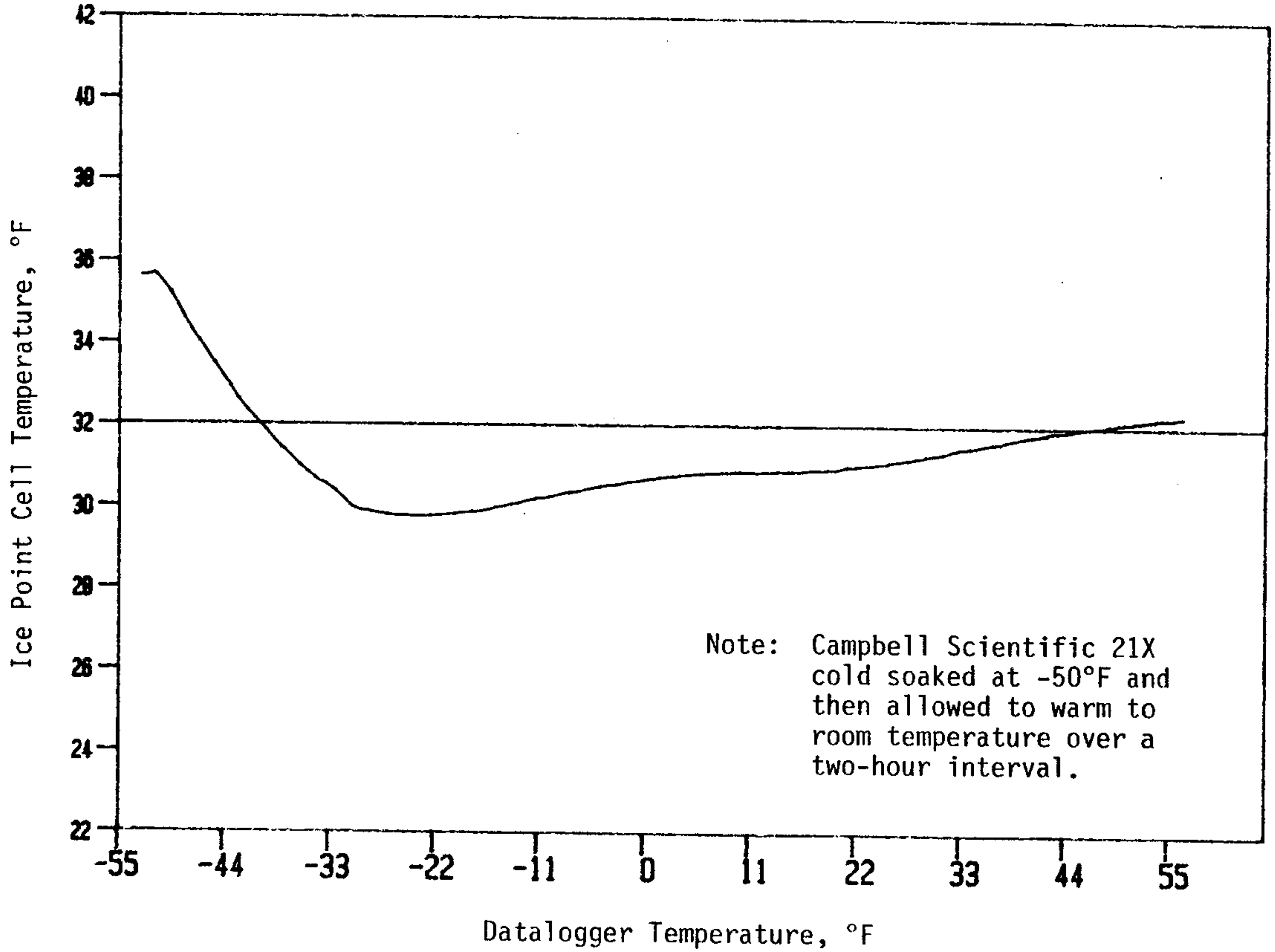


Figure 4. Campbell accuracy as a function of temperature during a warming cycle.

Test cycle 4 using a newer Campbell Scientific 21X showed none of the highly random data storage that was typical of the other test cycles.

The Metrosonics dl-721 datalogger appeared to be more sensitive to large temperature gradients than the Campbell Scientific 21X. During the first test, the datalogger operated to about -30°F (apparently it could not sustain a 10°F temperature gradient between it and the cold chamber and also operate below about -30°F). During the third test, the datalogger could not withstand a 5°F internal temperature gradient and operate below about -30°F. During the fourth test, the Metrosonics dl-721 unit operated continuously and accurately at -40°F (it had to be cooled to -40°F very slowly due to its low resistance to internal temperature gradients). It was warmed rapidly and all the test data were lost when a hard reset was performed. During the fifth test, the datalogger temperature was reduced very slowly, and an attempt to retrieve data was made at -20°F. The previously routine act of retrieving information with an IBM-PC microcomputer at datalogger temperatures above -30°F was enough to initiate failure. Continued extensive testing is needed to determine the full extent of degraded operating characteristics due to thermal cycling, cold temperatures and internal temperature gradients.

While neither unit operates reliably below about -30°F, our limited test data suggest that the Campbell Scientific 21X possesses more operating integrity at reduced temperatures than the Metrosonics dl-721. The Campbell Scientific 21X has internal alkaline batteries that are operable only to about -20°F. However, a separate gel cell battery pack rated to -40°F or as another alternative, a 12 volt lead-acid battery can be used. To alleviate the problems associated with cold weather operation, we recommend that a subgrade, moisture-proof, insulated box be used to house the datalogger during data collection. If a datalogger is buried at a minimum depth of one foot in the soil under an insulating blanket or undisturbed snow cover, it should remain well above its -30°F safe operating temperature.

The second aspect of determining which datalogger is best suited for use by DOT&PF was user friendliness. In this category, the Metrosonics dl-721 holds a large edge over the Campbell Scientific 21X. The two significant factors that make the Metrosonics datalogger more user friendly than the Campbell Scientific datalogger are complete documentation and an on-screen program menu when interfaced to an IBM-PC microcomputer. The Campbell Scientific 21X has poor documentation and less than convenient programming logic. As an example, to set the time on the Metrosonics requires only a quick look at the menu. If one desires to set the time and date on the Campbell Scientific, a person may spend literally a couple of hours thumbing through the published users' manual. Without direct communication with Campbell Scientific, Inc., it is doubtful that a person with average programming skills could learn to use the Campbell to its fullest potential.

Both dataloggers can be programmed via an IBM-PC microcomputer. The Campbell Scientific 21X does have a few built-in features superior to the Metrosonics. For instance, the Campbell datalogger is capable of reading thermal EMFs (the signal generated by a thermocouple) and converting it directly to a temperature using an internal reference junction temperature. The built-in junction eliminates the need for separate electronic reference junctions. Furthermore, it eliminates the possibility of external electronic reference junctions introducing additional error due to their own internal electronic limitations or battery failure in cold temperature. Additional features on the Campbell Scientific 21X include: (1) reading pulsed inputs for event counting used in rain gauges, wind anemometers, etc.; (2) providing A.C. excitation for transducers such as soil moisture blocks that do not tolerate polarization; (3) providing excitation powering 1/4, 1/2 or full bridge transducers such as load cells, pressure transducers, etc.; and (4) providing six-bit digital control of relays, motors, etc. The Metrosonics dl-721 will record only voltage or current, and if the data being sought are linearly proportional to voltage or current, then the datalogger can be programmed to perform the engineering unit conversion. Where accuracy is desirable, thermal EMFs should be converted to temperatures using a high order polynominal curve fit. Unlike the Campbell Scientific 21X, the Metrosonics dl-721 will only accept linear conversions. The Campbell Scientific 21X has polynominal regressions in ROM for types T, E, K or J thermocouples. If a transducer is used for which the Campbell Scientific 21X doesn't have a built-in curve fit, the user may specify and program the curve fit. Furthermore, the Campbell

Scientific 21X has a host of programmable mathematical functions available.

Regardless of which unit is selected, it is necessary to take some action to safeguard the datalogger from the temperature extremes experienced in much of Alaska. Two possible courses of action are: (1) use of a heating device to keep the datalogger warm; or (2) use of a waterproof, subgrade well-insulated box to house the datalogger below ground or snow cover. By using a watertight container buried below an undisturbed snow cover and running a power and communications cable to the surface, accurate data should be continuously logged. Data could be retrieved at the surface using an IBM-PC microcomputer, cassette tape recorder or RS232C printer.

If the Campbell Scientific 21X is chosen, we highly recommend that several employees of DOT&PF learn its programming logic and syntax. A short but complete and understandable users' manual should be provided by Campbell Scientific or developed by a second party under contract with DOT&PF. Such a manual should include several types of programs that could be easily copied. Finally, if the Campbell Scientific 21X fails in the field due to extremely cold temperatures (-40°F), it is unlikely that a manual reset or reprogramming will be required. Experience shows that it will store errant data at cold temperatures but will otherwise continue to function. Upon warming, the Campbell Scientific 21X will resume accurate datalogging and storage.

The only major precaution to using the Metrosonics dl-721 is that it is highly sensitive to the cold. If it fails to operate in the field, it will need to be reset manually and reprogrammed before any further data can be logged.

Two Campbell Scientific 21X dataloggers were installed in the field during September of 1985. Twelve volt lead-acid batteries are being used as power sources for the units. The dataloggers and batteries are housed in insulated boxes. Once a month the data have been retrieved on cassette tape and the lead-acid battery replaced with a fully charged one. As of February 1986, no failure has occurred with the Campbell Scientific 21X installed at Bonanza Creek, 30 miles south of Fairbanks on the Parks Highway. However, the unit installed along Farmer's Loop Road adjacent to the University of Alaska-Fairbanks campus stored errant data in October. Apparently this was caused by an overly discharged lead-acid battery. Upon replacing the battery, the unit worked properly.

ACKNOWLEDGMENTS

Rick Briggs of DOT&PF helped us with testing the dataloggers and wrote the program in Appendix C.

APPENDIX A

Metrosonics dl-721 Datalogger

SPECIFICATIONS

SUMMARY OF KEY FEATURES

1. Full ASCII keyboard.

2. Special function keys including command keys: PROGRAM, DISPLAY, OUTPUT, CHANNEL, SYSTEM and TIME. Additional special function keys are: TERMINAL, REMOTE, ON/OFF, RUN/STANDBY, ROLL SELECT, the UP arrow, the DOWN arrow, the RIGHT arrow and the LEFT arrow.

3. R5-232C compatible serial interface with six programmable baud rates: 300, 600, 1200, 2400, 4800 and 9600.

4. 40 character (20 x 2) liquid crystal display.

5. Water-tight to permit installations in harsh environments.

6. Internal rechargeable sealed lead-acid battery.

7. Will operate on external power source.

8. One week of operational battery life, when sampling at a rate of five seconds/sample.

9. Two months of battery backup.

10. Automatic powerdown feature when not in use, or when battery voltage is too low.

11. Output available in formatted user-defined units.

12. Real-time clock allows user to schedule time of data collection.

13. Ability to log on alarm exceedance.

14. Ability to signal alarm condition through a contact closure.

15. Maintenance of run-time statistics of AVERAGE, MINIMUM and MAXIMUM to be viewed at any time during data collection.

16. Ability to perform as a remote terminal; used in logging on and off remote computer facilities.

17. Ability to be programmed remotely via the R5-232C interface.

18. Capable of storing 8180 time history statistics with the 16K standard memory.

SUMMARY OF PROGRAMMABLE FEATURES

1. Select any combination of channels to be off or on. By "on" it means that the "on" (active) channel will log data.

2. Select input in volts or mAmps (software corrects for external resistor when measuring current).

3. Select the maximum voltage (or current) input range for each channel.

4. Program user-defined-units; five characters defined by you will be displayed during output to the LCD or printer.

5. Calibrate each channel using either predefined calibration points or measuring the voltage at the channel input to generate two calibration points. Using two calibration points, the dl-721 will calculate a true mx + b scaling to user defined engineering units.

6. Select what time history data to save. Any combination of averages, minimums and maximums for each channel can be programmed.

7. Select to collect amplitude distribution data on any combination of active channels.

8. Program upper and lower alarm levels for each channel in engineering units.

9. Select what data to print when a printout is requested. Each channel can be programmed individually to dump the current input range, scaling factors, time history statistics and amplitude distribution statistics.

10. You can clear memory any time that the dl-721 is not logging data.

11. Select one of six possible sampling rates: 4/sec, 1/sec, 2 sec, 5 sec, 10 sec or 1/min.

12. Select an averaging time, ranging from one average calculation per second up to one average calculation per day.

13. Enable or disable alarm logging.

14. Select baud rates (300, 600, 1200, 2400, 4800 and 9600).

15. Program four lines, 20 characters per line, of header information that will be printed out during formatted output.

16. Select formatted or unformatted output. Formatted output will display header information, and will print out the time history and amplitude distribution data in semi-graphical format. Unformatted output will print out the stored data in condensed form.

17. Program the number of time history periods to be combined on a formatted time history report.

18. Select format of output for either a 48 column or 80 column printer.

19. Program date and time.

20. Select the type of schedule run. MANUAL run means that the dl-721 will start collecting data as soon as the LOG/STBY key is pressed; DAILY run means that the dl-721 will start collecting data at a preprogrammed start time and stop at a preprogrammed stop time, on a daily schedule; 1 TIME means that the dl-721 will start collecting data at a preprogrammed start date and time and stop collection at a preprogrammed stop date and time.

21. Program the schedule of a data collection period, either for DAILY collections or 1 TIME collections.

APPENDIX B

Campbell Scientific 21X Datalogger

SPECIFICATIONS

SPECIFICATIONS

The following electrical specifications are valid for an ambient temperature range of −25 deg. C to +50 deg. C unless otherwise specified.

ANALOG INPUTS

NUMBER OF CHANNELS: 8 differential or up to 16 single ended using one differential channel for each two single ended channels.

CHANNEL EXPANDABILITY: The Model AM32 Relay Scanner multiplexes 32 differential channels through a single 21X differential channel. Up to 6 AM32 scanners can be added to a 21X for 192 additional analog channels.

VOLTAGE MEASUREMENT TYPES: Single-ended or differential. A thermistor at the input terminals provides reference junction compensation for thermocouple measurements.

ACCURACY OF VOLTAGE MEASUREMENTS AND ANALOG OUTPUT VOLTAGES: 0.1% of FSR, 0.05% of FSR (0 to 40 deg. C).

RANGE AND RESOLUTION: Ranges are software selectable for any channel. Resolution for single ended measurements is twice the value shown.

Full Scale Range	Resolution
±5 volts	333. microvolts
±0.5 volts	33.3 microvolts
±50 millivolts	3.33 microvolts
±15 millivolts	1. microvolt
±5 millivolts	0.33 microvolts

INPUT SAMPLE RATES: The fast A/D conversion uses a 250us signal integration time and the slow conversion uses a 16.666ms signal integration time (one power line cycle period). Differential measurements include a second sampling with reversed input polarity to reduce thermal offset and common mode errors. The following intervals do not include the self-calibration measurement which occurs once per instruction. Input sample rates should not be confused with system data throughput rates.

Fast single-ended voltage:
2.4 milliseconds/channel
Fast differential voltage:
3.7 milliseconds/channel
Slow single-ended voltage:
18.8 milliseconds/channel
Slow differential voltage:
37.0 milliseconds/channel
Fast differential thermocouple:
7.3 milliseconds/channel

INPUT NOISE VOLTAGE:
Fast differential — 0.83 microvolts RMS
Slow differential — 0.1 microvolts RMS

COMMON MODE RANGE: ±5 volts.

COMMON MODE REJECTION: >140 dB (DC to 100 Hz).

NORMAL MODE REJECTION: 70 dB (60 Hz with slow differential measurement).

INPUT CURRENT: 2 nanoamps max.

INPUT RESISTANCE: 200 gigohms

ANALOG OUTPUTS

NUMBER OF ANALOG OUTPUTS: 4 switched, 2 continuous.

DESCRIPTION: Switched and continuous. A switched output is active only during a measurement and is swtiched off (high impedance) immediately following the measurement. Only one switched output can be active at any one time. The 2 continuous outputs hold a preset voltage until updated by an analog output command.

RANGE: ±5 volts.

RESOLUTION: 0.67 millivolts.

ACCURACY: Same as voltage input.

OUTPUT CURRENT: 20 mA at ±5 volts, 50 mA at ±2.5 volts.

RESISTANCE AND CONDUCTIVITY MEASUREMENTS

ACCURACY: 0.035% (0.02% 0 to 40 deg. C) of full scale bridge output provided the matching bridge resistors are not the limiting factor. The excitation voltage should be programmed to match the bridge output with a full scale input voltage range.

MEASUREMENT TYPES: 6 wire full bridge, 4 wire full bridge, 4 wire, 3 wire and 2 wire half bridge. High accuracy, low impedance bridge measurements are ratiometric with dual polarity measurements of excitation and output to eliminate thermal emfs. AC resistance and conductivity measurements use a 750us excitation pulse with the signal integration occurring over the last 250us. An equal duration pulse of opposite polarity is applied for ionic de-polarization.

PULSE COUNTERS

NUMBER OF PULSE COUNTER CHANNELS: 4 eight bit or 2 sixteen bit, software selectable.

MAXIMUM COUNT RATE: 2550 Hz, eight bit counters; 250 kHz, sixteen bit counters. Pulse counter channels are scanned at a maximum rate of 10 Hz.

MODES: Programmable modes are switch closure, high frequency pulse and low level AC.

SWITCH CLOSURE MODE
MINIMUM SWITCH CLOSED TIME:
3 milliseconds.
MINIMUM SWITCH OPEN TIME:
4 milliseconds.
MAXIMUM BOUNCE TIME:
1 millisecond open without being counted.

HIGH FREQUENCY PULSE MODE
MINIMUM PULSE WIDTH:
2 microseconds.
MAXIMUM INPUT FREQUENCY:
250 kilohertz.
VOLTAGE THRESHOLDS:
The count is incremented when the input voltage changes from below 1.5 volts to above 3.5 volts.
MAXIMUM INPUT VOLTAGE:
±20 volts.

LOW LEVEL AC MODE
This mode is used for counting frequency of AC signals from magnetic pulse flow transducers or other low voltage, sine wave outputs.

MINIMUM AC INPUT VOLTAGE:
6 millivolts RMS
INPUT HYSTERESIS:
11 millivolts.
MAXIMUM AC INPUT VOLTAGE:
20 volts RMS.
FREQUENCY RANGE:

AC Input Voltage (RMS)	Range
6 millivolts	1 Hz to 100 Hz
10 millivolts	0.5 Hz to 1000 Hz
20 millivolts to 20 volts	0.3 Hz to 2000 Hz

(consult factory if higher frequencies are desired)

DIGITAL CONTROL OUTPUTS

The 21X includes 6 digital control outputs that can be set or reset on command.

OUTPUT VOLTAGES
(no load): High — 5 volts ±.1 volt,
Low — <0.1 volt.

OUTPUT RESISTANCE:
400 ohms.

TRANSIENT PROTECTION

All input and output connections are protected using spark gaps connected directly to a heavy copper bar on the circuit card between the two input terminal strips. The 12 volt power input and charger inputs are protected with transzorbs.

CPU AND INTERFACE

PROCESSOR: HITACHI 6303 CMOS 8 bit microprocessor.

MEMORY: 16k ROM, 4k RAM, expandable in increments of 8k of RAM or ROM up to a total of 64k. Standard 21X stores 768 low resolution data points in Final Memory, 19,200 data points with fully expanded RAM.

DISPLAY: 8 digit LCD (0.5" digits).

PERIPHERAL INTERFACE: 9 pin D-type connector on the panel for connection to cassette recorder, modem, printer, or RS232 adapter. The serial interface can be programmed for baud rates of 300, 1200, 9600 and 76,800.

CLOCK ACCURACY: ±1 minute per month.

MAXIMUM PROGRAM EXECUTION RATE: The 21X Programming Table can be executed in sync with real time at a maximum rate of 80 per second. Typical throughput rates allow 1 measurement with linear scaling and transfer to tape at this rate with no interruption.

SYSTEM THROUGHPUT: Data throughput is the rate at which a signal can be measured, processed and stored in Final Memory. The rate is reduced by additional processing or when data is transferred to Cassette Tape or through the 21X serial port.

Throughput to the cassette tape is 100 data values per second. During tape transfer, 25% of the CPU's time is required. Therefore, program execution is uninterrupted if the user-entered program requires less than 75% of the CPU's time.

ASCII data values (10 characters per value) can be transmitted via the serial port at 9600 baud with a throughput of approximately 100 values per second with 15% CPU utilization. Faster throughput rates are possible if CSI's binary format is transmitted (consult factory).

Each time a new measurement instruction is specified, time for two additional measurements is required for self-calibration. Therefore, using more repetitions in fewer instructions increases throughput.

SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 15 volts.

TYPICAL CURRENT DRAIN: 1.0 mA quiescent, 25 mA during processing, and 60 mA during analog measurement.

INTERNAL BATTERIES: 8 Alkaline D cells with 7 amp hour capacity. The Model 21XL includes sealed lead acid batteries with 2.5 amp hour capacity per charge.

EXTERNAL BATTERIES: Any 12 volt external battery can be connected as a primary power source with the internal batteries providing backup while changing external batteries.

OPERATION FROM OTHER SOURCES: The Model 21XL includes a battery charging circuit that can be connected to 14 VAC (RMS) or 15 to 30 VDC indefinitely to maintain a full charge on the batteries without degradation. The charging circuit includes temperature compensation for maintaining optimum charging voltage at temperature extremes. A 110/220 VAC to 14 VAC wall transformer is provided with the 21XL.

PHYSICAL SPECIFICATIONS

SIZE: 8.2" X 5.7" X 3.3". Input terminal strips extend 0.45" above the panel surface

WEIGHT: 5.6 lbs.

APPENDIX C

Example Program for Campbell Scientific 21X Datalogger

This program makes hourly readings on eight type T thermocouples, once a day (at midnight). The Julian day, maximum, minimum and mean daily battery voltage, solar panel temperatures and T/C temperatures are output to final storage.

```
01:00        Program table 1
01:3600.0    1 hr (3600 sec) execution interval
01:P10       Measure battery voltage
01:0001      Store in loc 1
02:P17       Measure panel temperature
01:0002      Store in loc 2
03:P14       Measure temperature-T/C difference
01:08        3 repetitions
02:01        Range:  5mV, slow
03:01        Input channel for first T/C
04:01        T/C type (T)
05:0002      Location of reference temperature (2)
06:0003      Store first T/C temperature in loc 3
07:1.0000    Multiply by 1 (m)
                                   V = mx+b
08:0.0000    Offset (b)
04:P92       If time
01:0000      Time into interval
02:1440      Interval in min (24 hours)
03:10        Command:  set flag Ø
05:P77       Option:  real time
01:0100      Store Julian day
06:P73       Maximize
01:10        10 repetitions
02:00        Don't store time
03:0001      Start with loc 1
07:P74       Minimize
01:10        10 repetitions
02:00        Don't store time
03:0001      Start with loc 1
08:P71       Average
01:10        10 repetitions
02:0001      Start with loc 1
09:P00       End of program
```